Neutron Scattering Studies of Magnetism and Superconductivity in La_<2-x> Sr_x CuO_4 and (Nd, Pr)_<2-x> Ce_x CuO_4(Abstracts of Doctral Dissertations)

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Neutron Scattering Studies of Magnetism and Superconductivity in $La_{2-x}Sr_xCuO_4$ and $(Nd,Pr)_{2-x}Ce_xCuO_4$

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Abstract

Chap. I. Structure, Properties and Theory

An overview of the physical properties of the $La_{2-x}Sr_xCuO_4$ and $(Nd,Pr)_{2-x}Ce_xCuO_4$ systems is presented. A review of the neutron scattering experimental technique, along with other experimental details, is presented.

Chap. II. Crystal Growth and Heat Treatment

Single crystals of $Pr_{2-x}Ce_xCuO_4$ were grown using the CuO flux method. Large crystals in which the Ce distribution was homogeneous were grown over a wide range of Ce concentrations. Typically, the Pr_2CuO_4 and $Pr_{1.86}Ce_{0.14}CuO_4$ single crystals had dimensions 50ϕ X 3 mm^3 and 10 X 10 X 0.1 mm^3, respectively. A small but high quality reduced $Pr_{1.86}Ce_{0.14}CuO_4$ crystal shows superconductivity with a Tc of 18K and a transition width of 1.5K. The effects of Pt contamination from the Pt crucible have been examined. A 1% substitution of Pt for Cu eliminates the superconductivity entirely. Pt suppresses Tc more quickly in the $Pr_{2-x}Ce_xCuO_4$ system than $La_{2-x}Sr_xCuO_4$ system, where a Pt substitution of 2% eliminates the superconductivity. Suitable heat treatment condition have been determined in order to convert samples as throughly as possible to the superconducting phase.

Chap. III. Antiferromagnetism of Nd_2CuO_4 and Pr_2CuO_4

Antiferromagnetic long-range order of the Cu^{2+} moments develops below T_N=255K in both compounds. In Nd_2CuO_4 a series of magnetic phase transitions in which the Cu^{2+} spins reorient has also been observed below T_N, while in Pr_2CuO_4 the 3D Cu^{2+} spin structure is stable. No changes in the crystalline structure associated with the spin-reorientation transitions were found. Ordering of the rare-earth magnetic moments has been observed in both compounds. The $Nd^{3+}(Pr^{3+})$ magnetic moments align parallel (antiparallel) to the Cu^{2+} moments which are nearest neighbors along the c axis, and the

ordered moments of the rare-earth ions were determined to be ~1.3μ_B for Nd^{3+} at 0.4K and ~0.08μ_B for Pr^{3+} at 8K. The temperature-dependent moment is shown to be proportional to the Cu^{2+} moment times the bulk susceptibility. The temperature dependence of the 2D magnetic correlation lengths in both compounds is similar in chracter to that observed in pure and lightly doped La_2CuO_4. The heat treatment dependence of 3D and 2D magnetic correlations has also been shown.

Chap. IV. Antiferromagnetism of $(Nd,Pr)_{2-x}Ce_xCuO_4$

Measurements are reported of the static, instantaneous and dynamic spin correlations in single-crystals of $(Nd,Pr)_{2-x}Ce_xCuO_4$. The as-grown crystals show antiferromagnetic long range order. However, the Neel temperatures and spin stiffness constants are dramatically reduced from their respective values in Nd_2CuO_4 and Pr_2CuO_4. Thus, it is found that there are significant differences in the magnetic behavior of doped but nonsuperconducting doping hole- and electron-doped systems. These differences seem to originate primarily in the difference between magnetic frustration and dilution. After reduction and annealing a $Nd_{1.85}Ce_{0.15}CuO_4$ was made to be superconducting with T_c=23K. The empirical effect of deoxygenation is to inhibit the magnetic correlations so that the inverse magnetic correlation length is at least 0.1 rlu. Superconductivity then occurs in this highly disordered magnetic state.

Chap. V. Summary

The study is summarized.

Appendix

I. Antiferromagnetism of $La_{2-x}Sr_xCuO_4$

Neutron scattering experiments have been performed to study the dynamic spin properties of $La_{2-x}Sr_xCuO_4$ in a spin glass regime crystal (x=0.02) and a metallic regime crystal (x=0.10). In the spin glass regime crystal, which has no three-dimensional long range magnetic order above 8K, a gap in the spin-wave-like excitations due to out-of plane anisotropy forms below 50K. The integrated susceptibilities $\int dq_{2D}\ \mathrm{Im}\ \chi_{2D}(q_{2D},\omega)$ of both the spin glass regime and the metallic regime crystals follow the scaling function of ω/T suggested by Keimer et al., although the peak shapes of the scattering are different between the crystals.

II. Crystal Properties

The properties of crystals studied in this thesis are summarized.